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GB 2284100 A **GB 2090702 A** **GB 1503867 A**
EP 0589785 A1 **EP 0275960 A2** **US 4445183 A**

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(54) **AC electric power switching arrangement; avoiding inrush currents in inductive loads**

(57) The arrangement has a first switch 18 connected in parallel with a second switch 20 between an AC supply 12 and a load 14, particularly a transformer fed load, and control means to switch the load on by initially turning the second switch 20 on in a supply-synchronised manner and substantially immediately thereafter turning the first switch 18 on, the load being switched off by turning off switch 18 then switch 20. The arrangement may be used for a transformer fed industrial furnace having resistive heating elements with duty cycle power control. The switch 18 may be solid state but is preferably a contactor, and the second switch 20 may be formed by thermionic devices, MOSFETs, IGBTs or particularly thyristors. For a three phase supply with a R-Y-B phase sequence, a four step turn on sequence may be used. In step 1, the R and B thyristors are turned on at 30 - 90 degrees after a positive going zero crossing of the R-B voltage waveform; in step 2, the Y thyristors are turned on 150 degrees after the R-B voltage positive going zero crossing; in step 3, the contactor 18 is closed; and in step 4, the R, Y and B thyristors are turned off. To turn the load off, the R, Y and B thyristors are all turned on, then the contactor 18 is opened, then the Y thyristors are turned off at zero current flow on the positive going edge of a current cycle, and then the R and B thyristors are turned off at zero current flow on the next positive going edge of the R-B current cycle.

Alarms may be provided for loss of any supply phase, loss of phase reference, loss of power to the contactor operating coil, change in phase rotation, and change in operating frequency.

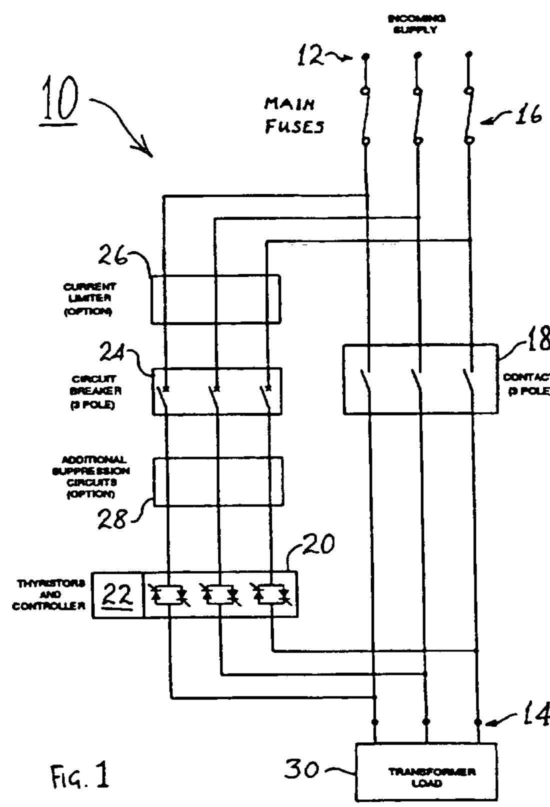

FIG. 1

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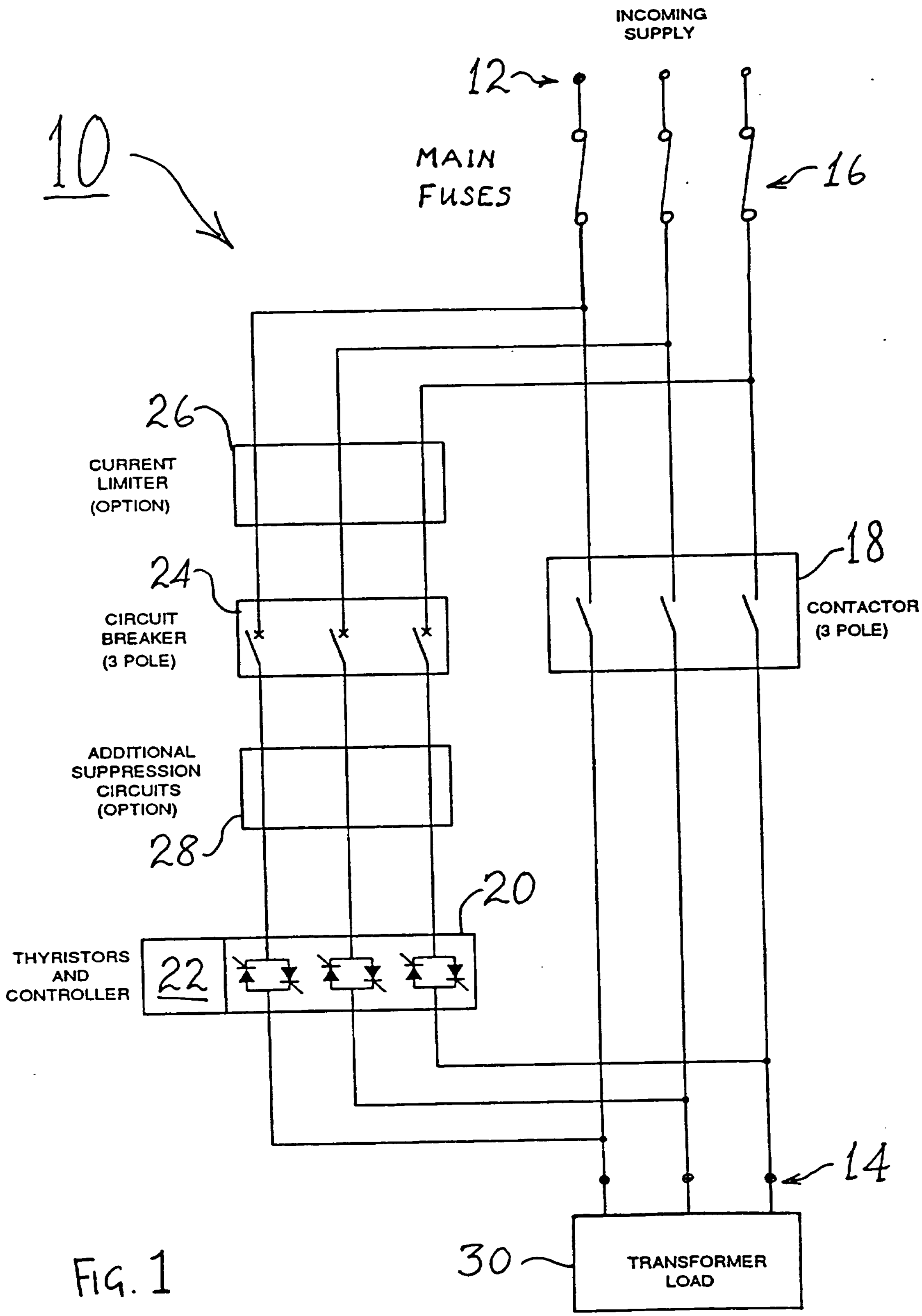

INCOMING SUPPLY
12
10
MAIN FUSES
16
26
CURRENT LIMITER (OPTION)
18
24
CIRCUIT BREAKER (3 POLE)
CONTACTOR (3 POLE)
ADDITIONAL SUPPRESSION CIRCUITS (OPTION)
28
20
THYRISTORS AND CONTROLLER
22
14
30
TRANSFORMER LOAD

FIG. 1

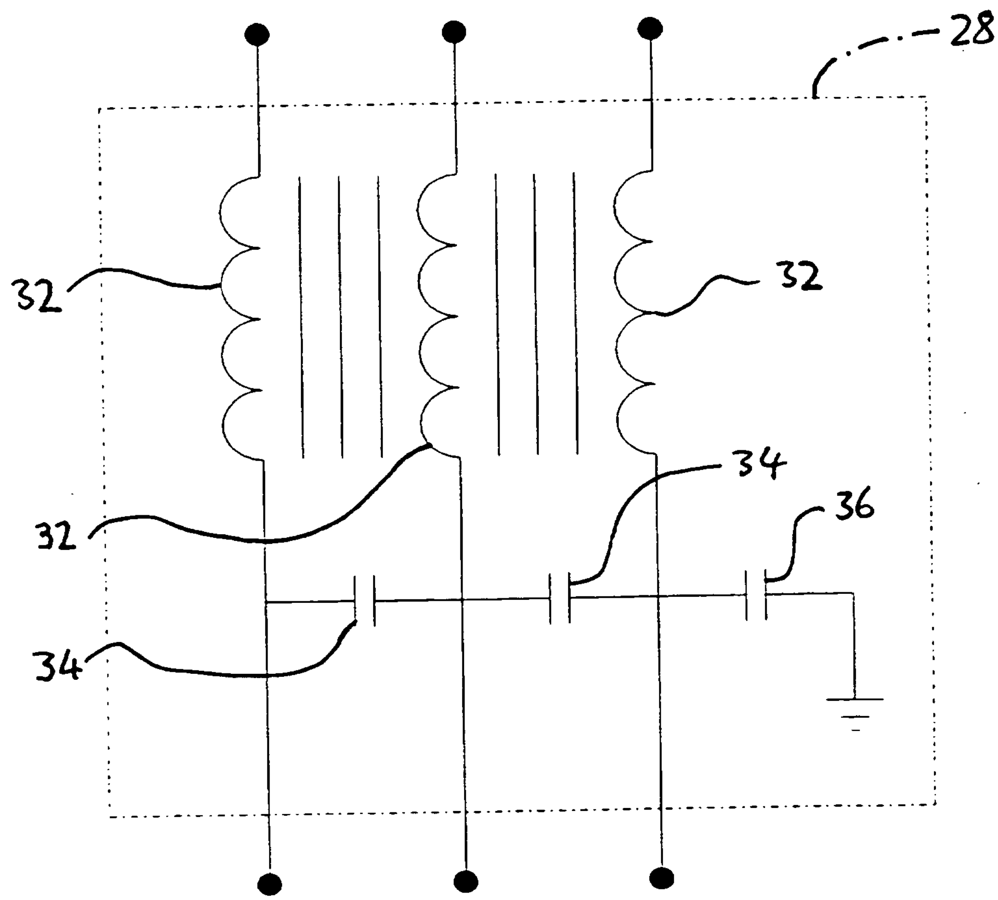

FIG. 2

"Electric Power Switching Arrangements"

This invention relates to electric power switching arrangements for controlled switching of AC power from a supply to a load, and relates more particularly but not exclusively to electric power switching arrangements for controlled switching on and/or off of AC power to a load coupled to the AC power supply through a transformer which is connected between the switching arrangement and the load, or which forms part of the load.

To control the temperature of an electrically energised heating load, the AC power input to the load must be controlled. In its simplest form, control may be effected by switching the AC supply to the load on and off in a controlled manner, adjusting the duration of the "on" time periods relative to the duration of the "off" time periods. If the load temperature is to remain broadly constant, the on/off switching frequency must be fast enough to prevent the load temperature fluctuating upwards and downwards by excessive amounts with the "on" and "off" cycling. For an industrial furnace, a typical power switching frequency might be of the order of four on/off cycles per minute. The

simplest switch means is an electromechanical contactor, and such switches are widely used in low cost resistive heating applications. The major disadvantage with electromechanical contactors is contact wear, which can result in an unacceptably short life at the operating frequencies involved (ie several hundred contactor operations per hour). A further disadvantage with electromagnetic contactors lies in the switching action causing electromagnetic interference due to arcing at the contacts.

When a contactor is utilised to switch a transformer-coupled load, the arcing at the contacts is even more severe than when the contactor is switching a directly connected resistive load of comparable kVA rating. Additionally, there is potentially a large inrush current each time the transformer is switched on. These technical problems preclude the use of contactors for switching transformers at the repetition rate required for temperature-controlled heating loads, since the repetitive current inrushes would result in overheating of the transformer, and contact arcing (especially at switch-off) would unacceptably shorten contact life.

It has been proposed to control AC heating loads by means of thyristors. (A thyristor is a well-known form of gate-controlled semiconductor switch). Thyristors have no physical wear mechanisms comparable to those of an electromagnetic contactor with its moving parts and current-breaking contacts. In the case of resistive loads, thyristors can be used to provide zero-voltage switching on and off, thus almost eliminating the generation of electromagnetic interference by load switching operations. However, with a transformer-coupled load, zero-voltage switching by thyristors is

not feasible since it results in a high inrush current.

It has been proposed to utilise thyristors to control transformer-coupled loads by operating the thyristors in "phase-angle" mode, wherein individual half-cycles of the AC supply are switched on at a controlled phase angle with respect to the preceding zero-crossing thereby to chop the supply and thus to control the main load current. However, use of thyristors as "choppers" or phase-angle power controllers results in high levels of electromagnetic interference, harmonic distortion of the supply current, and a low power factor; for these reasons phase-angle control is becoming increasingly unacceptable as a method of control, unless phase-angle control is necessary to fulfil other process requirements.

A proposed variation of phase-angle control of thyristors is known as "soft-start burst fire" wherein the supply is switched on and off in bursts of a number of cycles, with the first few cycles in each "on" burst being subjected to phase-angle ramping up to minimise inrush. Soft-start burst fire results in a reduced but still significant level of interference generation.

Another technique proposed for controlled switching of transformer-coupled loads consists of synchronised switching with delayed firing angle. Assuming no prior magnetisation of a transformer core, it can be proved mathematically that the inrush to a single-phase load will be zero if switch-on occurs at the peak of the supply voltage waveform. This principle can be exploited by utilising thyristors. The load must, however, be switched off in a manner which either minimises transformer magnetisation or results in consistent transformer magnetisation, in order that the

arrangement can be switched on at an empirically determined point just prior to the supply voltage waveform peak at which the inrush will be minimised. A particular problem of uncontrolled inrushes can arise with this technique if the transformer is incorrectly switched off, for example due to a noisy supply, a supply failure, manual opening of the supply isolator, etc. Similar unwanted effects can arise if the installation is modified, or if there is an alteration of phase sequence or operating frequency.

Spurious inrushes can result in failure of the special semiconductor protection fuses, or if a fuse does not immediately blow in response to a current surge, its life is likely to be reduced significantly, resulting in early failure through fatigue (which is aggravated by rapid on-off switching).

Thyristor equipment for control of high current loads (75 Amperes and upwards) is bulky, due to the large heatsinks required to dissipate the heat losses in the thyristors. Fans may be required to remove heat from the sinks, and these considerations can result in an assembly which is relatively complex and heavy, and which may be difficult to maintain. As an alternative to air cooling, water cooling may be employed but this is also complex.

In the use of thyristors for switching on loads, it is not possible to detect and correct for inrushes, since once the thyristor becomes conductive, the thyristor cannot be switched off again until the current passing through the thyristor is reduced to zero which will only occur at the next zero crossing of the supply current waveform in supply-commutated systems. Semiconductor devices other than thyristors are

available which could possibly be employed for current limitation. At present the cost and power losses of such devices generally preclude their use in high current applications.

It is therefore an object of the invention to provide an electric power switching arrangement for controlled switching of AC power to a load, which arrangement obviates or mitigates one or more of the above-described disadvantages.

According to a first aspect of the present invention there is provided an electric power switching arrangement for controlled switching of AC power from an AC power supply to a load, said switching arrangement comprising input terminal means connectable to the AC power supply, output terminal means connectable to the load, first switch means operable to connect said input terminal means and said output terminal means, second switch means electronically operable electrically to connect said input terminal means to said output terminal means, said first and second switch means being so connected as to provide electrically parallel paths for AC power from said input terminal means to said output terminal means, said switching arrangement further comprising control means operable during use of the switching arrangement to switch on AC power from the supply to the load by switching said second switch means into an electrically connective state in a controlled manner which is supply-synchronised and substantially immediately thereafter to operate said first switch means into a connective state, and vice versa upon switch-off.

Said second switch means may be switched into an electrically connective state substantially at a

predetermined phase-angle in the voltage waveform of the AC supply.

Said first switch means may be a solid-state switch means, but said first switch means is preferably a switch means which is mechanically operable conductively to connect said input terminal means to said output terminal means. Said control means is preferably such that during switch-on, said second switch means is switched into an electrically non-conductive state subsequent to operation of said first switch means into a conductively connective state, whereby said first switch means thereafter carries the totality of electric power from the supply to the load, and vice versa upon switch-off.

Said first switch means is preferably a contactor which may be electromagnetically operable by means of a solenoid arrangement. The contactor preferably includes a respective closable contact arrangement in each pole of the supply, with each said closable contact arrangement operating substantially simultaneously.

Said second switch means is preferably a semiconductor switch means which may comprise a respective pair of anti-parallel-connected thyristors in each pole of the supply. Alternative forms of semiconductor switch comprise transistors such as (for example) IGBTs (insulated gate bipolar transistors), MOSFETs (metal-oxide/semiconductor field effect transistors), and the like. Said second switch means may alternatively be an electronically controllable non-semiconductor switch, for example a thermionic device such as a thyratron or a grid-controlled mercury arc rectifier.

Said second switch means (of whatever form) may be electrically connected in series with current interruption means (such as a circuit breaker means or high breaking capacity fuses) between the input terminal means and the output terminal means whereby to provide protection against full currents.

According to a second aspect of the present invention there is provided a combination of an AC power switching arrangement and a load-coupling means, said AC power switching arrangement comprising an electric power switching arrangement according to the first aspect of the present invention, said load-coupling means being connected to receive controlled AC power from the output terminal means of the electric power switching arrangement, and said load-coupling means being connectable to deliver controlled AC power to a load.

Said load-coupling means preferably comprises a transformer.

Embodiments of the invention will now be described by way of example, with reference to the accompanying drawings, in which:

Fig. 1 is a block schematic diagram of a first embodiment of the invention; and

Fig. 2 is a schematic diagram of an interference suppression circuit which may be incorporated into the embodiment of Fig. 1.

Referring to the drawing, an electric power switching arrangement 10 is a 3-phase 3-wire AC system having input terminals 12 and output terminals 14. The

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high breaking capacity gL fuses, connected in series with the group 20 in the power path paralleling the power path through the contactor 18. The circuit breaker or fuses 24 also provide thermal protection for the cabling associated with the power path through the thyristor group 20.

The power path through the thyristor group 20 may optionally include further functional entities, for example a current limiter 26 and/or an interference suppression circuit 28. The interference suppression circuit might, for example, comprise a common mode choke circuit as illustrated in Fig. 2, comprising three magnetically coupled coils 32 one of which is connected in each of the three-phase supply lines, together with first and second capacitors 34 connected between adjacent three-phase supply lines and a third capacitor 36 connected between one of the three-phase supply lines and earth.

For reasons to be explained below, the components included in the thyristor power path, including the cabling, circuit breaker/fuses 24, the limiter 26 and the suppressor 28, need not be rated to carry full load current continuously, beneficially resulting in reduced size, weight, and cost. Typically, these components need be rated at about only one fifth of the full load current.

The switching arrangement 10 has a 3-phase 3-wire transformer load 30 connected to the output terminals 16 to have the AC power thereto controlled in the manner about to be described. The transformer load 30 generally comprises load elements (for example, resistive heating elements; not illustrated) coupled to the terminals 16 through a transformer which carries

the entire power from the supply to the load elements.

The switching arrangement 10 varies the average consumption of electric power in the load 30 by switching AC power on and off, typically about 4 times per minute when equal "on" and "off" times are set (50% duty cycle). Load power consumption is controlled by modulating the ratio of "on" time to "off" time. The control circuit 22 is preferably programmed such that the modulating algorithm reduces the switching frequency progressively as the "on" period becomes a lesser or greater proportion of the duty cycle than the 50% duty cycle previously referred to, and also such that positive minimum "on" and "off" times are provided such that switching does not occur too frequently.

As previously discussed, electric power regulation can be effected by switching power on and off at a suitable repetition rate (eg several times per minute), but there are consequential adverse effects on the power switch. The present invention avoids or mitigates these undesirable effects by operating the thyristor group 20 to shunt the contactor 18 for short periods overlapping transitions between "closed" and "open" states of the contactor 18, and moreover avoids or mitigates the adverse electrical aspects of the load being a transformer load by suitably timing the gating of individual thyristors in the group 20, as will now be detailed.

In the following description it is assumed that the 3 phases are labelled "R", "Y", and "B", and that the phase sequence is "R-Y-B".

As a first step in the "on" switching sequence, the thyristors in the "R" and "B" phases are switched on

simultaneously, at a phase-angle determined empirically and in the range from 30° to 90° after positive-going zero crossing of the supply voltage waveform. The thyristors in the "Y" phase are next switched on 150° after the "R-B" positive-going zero crossing. The operating coil in the contactor 18 is then energised to cause the contactor 18 to commence to close (ie to switch "on" to its current-carrying conductive state). After a delay of sufficient duration as to ensure that the contactor 18 has closed and that contact bounce has terminated, all thyristors in the group 20 are switched off simultaneously. Thereby the switching arrangement 10 provides the benefits of controlled phase-angle switch-on to avoid excessive inrush, but requires the semiconductor elements involved to carry full-load current for such a brief period that the thyristors, and especially their cooling arrangements, circuit breaker or fuses 24, and cabling can be considerably de-rated below what is necessary to withstand full-load current on a continuous basis.

The switch-off sequence of the switching arrangement 10 is as follows: With the contactor 18 closed and conducting AC power from the input terminals 12 to the output terminals 14, all thyristors in the group 20 are simultaneously switched on. Next, the operating solenoid coil of the contactor 18 is de-energised to cause the contactor 18 to commence to open. After a delay of sufficient duration as to ensure that the contactor 18 is fully and continuously open, the thyristors in the "Y" phase are switched off at the point of zero current flow on the positive-going edge of the cycle. The thyristors in the "R" and "B" phases are then switched off simultaneously at the point of zero current flow on the next positive-going edge of their cycle.

Variants of these device switching sequences are possible without departing from the scope of the invention. For example, during switch-on, the thyristors for the "B" phase can be switched "on" prior to those for the "R" phase, provided the thyristors for the "R" phase are then controlled as previously detailed for the "R" and "B" phases together. In general, it is most important that the switching of the phases should always follow the same sequence, and be related. It is not satisfactory that (for example) the "Y" phase thyristors might sometimes switch off after the switching off of the thyristors for the "R" phase even if it is switched off at the same point in the cycle.

In a form of the switching arrangement 10 rated to carry 3-phase loads of up to 300A at 480V, the thyristors of the group 20 are switched on for a burst of approximately 140 milliseconds at the beginning and end of each "on" period. These units accept an input control signal of 1.5V or 4-20mA, and provide an integrated unit with all control circuitry, the thyristors, and an independent output to switch the contactor coil, with zero voltage switching. The unit modulates the load power by modulating the ratio of on to off time of the load, with a nominal switching frequency of 4 cycles per minute at 50% duty cycle, corresponding to an input of 3V (50% signal). The modulating algorithm reduces the switching frequency progressively as the "on" period becomes a lesser or greater proportion of the cycle, and provides positive minimum on and off times, so that the contactor is not switched on and off too rapidly. The units are microprocessor based and provide an extensive alarm strategy, covering the following:-

1. Loss of any supply phase.

2. Loss of phase reference (used for synchronising the switching action).

3. Loss of power to the contactor coil.

4. Change in phase rotation.

5. Change in operating frequency.

In the case of 1-3, if these events occur while power is applied to the load, the transformer may be left incorrectly magnetised, which could result in an inrush when power is next applied to the transformer.

4 and 5 would only apply when the unit is first switched on after alteration of the plant, and again could result in an inrush when power is next applied to the transformer.

Under these circumstances, to prevent the inrush from tripping the circuit beaker or fuses 24 which protects the thyristors 20, the contactor 18 is switched on once without thyristor assistance, the surge being passed through the contactor. So that these special switch-on requirements are not lost in the event of power loss, a non-volatile memory (EEPROM) is used to store the information prior to shutdown. (With standard thyristor equipment it is common practice to revert to a ramped phase-angle start for the first application of power after the unit has been switched off). There will inevitably be occasions when a surge is still passed through the thyristors, but with this apparatus an alarm will sound, and all that should be required is to reset the circuit breaker or replace the fuses 24,

rather than the expensive and time-consuming task of replacing semiconductor fuses.

In the case of 1, loss of a supply phase indicating the operation or failure of the circuit breaker or fuses 24, the apparatus may be adapted to switch to a "contactor-only" mode of operation, so that power continues to be supplied to the load 30 without the use of the switching arrangement 10. This is acceptable for limited time periods and allows an on-going job to be completed prior to remedial action being taken to restore the lost phase. An alarm draws attention to the fault, without shutting down the power supply altogether.

Advantages of the preferred embodiment of the invention are as follows:-

The invention is a solid state device, intended for use in conjunction with an electromechanical contactor, for switching transformer loads in the synchronous mode with delayed start angle. The contactor carries the main load current, but the thyristors are switched on briefly at the start and end of the "on" period, to provide switching which is synchronised to the supply frequency. This system provides significant benefits:-

1. The thyristors are smaller for a given load current, and the heat dissipation is very considerably reduced, resulting in a compact lightweight device of simple mechanical construction, which is readily replaced or repaired in the event of failure.

2. The contactor life is very much extended, because the contacts are not carrying the main load

current at the time of switching. This almost completely eliminates arcing.

3. The thyristors may be protected against the expected levels of fault current (limited by the transformer impedance) using a standard miniature or moulded case circuit breaker or HBC gL fuses. The circuit breaker or fuses also provide thermal protection for the reduced sized cabling associated with the thyristor device (typically 1/5 the full load current).

4. Levels of electromagnetic interference are low, as arcing in the contactor is suppressed by the thyristors.

5. The use of a contactor in association with the thyristor enables independent fail-safe action in the event of the short circuit of a thyristor, which might otherwise result in furnace overheating; an independent over-temperature sensor and control instrument may also be required.

The concept may be extended in the following ways:-

1. Further circuit elements to reduce electromagnetic interference may be incorporated in the low current thyristor path, where these devices would not require to be rated to carry the full load current. This could have a very significant size, weight and cost benefit. The circuit of Fig. 2 is one preferred example.

2. Devices other than thyristors could be used in conjunction with detection circuitry to limit

inrush or surge currents automatically. In this case the greater heat loss and expense of these devices would be offset by the smaller size of devices required due to the short conduction period. The use of insulated gate bipolar transistors (IGBT's) is a particularly preferred alternative to thyristors.

3. The concept is potentially applicable to other load types, when the switching characteristics would be modified to suit the load requirements.

4. The preferred form of device constituting the first switch means is preferably an electromechanically operated contactor, but other forms of mechanically operated switch may be employed such as (for example) pneumatically operated switches and hydraulically operated switches.

5. While the preferred form of the first switch means is a contactor, it is within the scope of the invention that the first switch means be some other type of switch means such as (for example) a solid state switch means, with the power path through said second switch means being used primarily to fit interference suppression devices of a lower current rating than is necessary on a basis of a continuous rating.

6. While the preferred operation of the second switch means is for the second switch means to be switched into an electrically connective state substantially at a predetermined phase angle in the voltage waveform of the AC supply, it is possible within the scope of the invention to

substitute other forms of controlled switching which are synchronised to the supply. This could (for example) allow the possibility of sensing inrushes and of controlling the point of switch-on accordingly. If employing IGBTs as the second switch means (thereby to be independent of current zeroes for device switch-off), it would be possible to chop the AC supply at a relatively high frequency (ie to switch the IGBTs on and off several or many times within each cycle of the supply), and by altering the mark/space ratio of this high frequency chopping, effectively limit the current taken by the load. The use of such devices is facilitated because the higher heat losses are mitigated by the short duration of the conduction periods. It might also be desired to use ramped phase-angle control, making use of the low current characteristic (in the longer term) of the AC power path through the second switch means to reduce the size of the associated suppression circuits.

Other modifications and variations can be adopted without departing from the scope of the invention.

Claims

1. An electric power switching arrangement for controlled switching of AC power from an AC power supply to a load, said switching arrangement comprising input terminal means connectable to the AC power supply, output terminal means connectable to the load, first switch means operable to connect said input terminal means and said output terminal means, second switch means electronically operable electrically to connect said input terminal means to said output terminal means, said first and second switch means being so connected as to provide electrically parallel paths for AC power from said input terminal means to said output terminal means, said switching arrangement further comprising control means operable during use of the switching arrangement to switch on AC power from the supply to the load by switching said second switch means into an electrically connective state in a controlled manner which is supply-synchronised and substantially immediately thereafter to operate said first switch means into a connective state, and vice versa upon switch-off.

2. An arrangement as claimed in Claim 1, wherein said second switch means may be switched into an electrically connective state substantially at a predetermined phase-angle in the voltage waveform of the AC supply.

3. An arrangement as claimed in Claim 2, wherein said second switch means comprises a semiconductor switch means.

4. An arrangement as claimed in Claim 3, wherein said semiconductor switch means comprises a respective pair

of anti-parallel-connected thyristors in each pole of the supply.

5. An arrangement as claimed in Claim 3, wherein said semiconductor switch means comprises transistors.

6. An arrangement as claimed in Claim 5, wherein said transistors comprise insulated gate bipolar transistors or metal-oxide/semiconductor field effect transistors.

7. An arrangement as claimed in Claim 2, wherein said second switch means comprises an electronically controllable non-semiconductor switch.

8. An arrangement as claimed in Claim 7, wherein said electronically controllable non-semiconductor switch comprises a thermionic device such as a thyratron or a grid-controlled mercury arc rectifier.

9. An arrangement as claimed in any preceding Claim, wherein said second switch means is be electrically connected in series with current interruption means between the input terminal means and the output terminal means whereby to provide protection against full currents.

10. An arrangement as claimed in Claim 9, wherein said current interruption means comprises circuit breaker means or high breaking capacity fuses.

11. An arrangement as claimed in any preceding Claim, wherein said first switch means comprises a solid-state switch means.

12. An arrangement as claimed in any one of Claims 1 to 10, wherein said first switch means comprises a

switch means which is mechanically operable conductively to connect said input terminal means to said output terminal means.

13. An arrangement as claimed in Claim 12, wherein said first switch means comprises a contactor which is electromagnetically operable by means of a solenoid arrangement.

14. An arrangement as claimed in Claim 13, wherein said contactor includes a respective closable contact arrangement in each pole of the supply, with each said closable contact arrangement operating substantially simultaneously.

15. An arrangement as claimed in any preceding Claim, wherein said control means is such that during switch-on, said second switch means is switched into an electrically non-conductive state subsequent to operation of said first switch means into a conductively connective state, whereby said first switch means thereafter carries the totality of electric power from the supply to the load, and vice versa upon switch-off.

16. An arrangement as claimed in any preceding Claim, wherein said second switch means is electrically connected in series with current limiting means.

18. An arrangement as claimed in any preceding Claim, wherein said second switch means is electrically connected in series with interference suppression means.

19. An arrangement as claimed in Claim 18, wherein said interference suppression means includes a common

mode choke circuit.

20. An arrangement as claimed in any preceding Claim, wherein said control means is adapted to activate an alarm and to switch said second switch off in response to loss of current in any one phase of said second switch means.

21. A combination of an AC power switching arrangement and a load-coupling means, said AC power switching arrangement comprising an electric power switching arrangement as claimed in any preceding Claim, said load-coupling means being connected to receive controlled AC power from the output terminal means of the electric power switching arrangement, and said load-coupling means being connectable to deliver controlled AC power to a load.

22. A combination of an AC power switching arrangement and a load-coupling means as claimed in Claim 21, wherein said load-coupling means preferably comprises a transformer.

23. An electric power switching arrangement substantially as hereinbefore described with reference to the accompanying drawings.

24. A combination of an AC power switching arrangement and a load-coupling means substantially as hereinbefore described with reference to the accompanying drawings.

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Patents Act 1977 **Examiner's report to the Comptroller under Section 17** **(The Search report)**	Application number GB 9520859.1
Relevant Technical Fields (i) UK Cl (Ed.N) H1N NSP, NSQ, NSS; H2H HAL, HAPA, HAPD, HHR3, HHR7 (ii) Int Cl (Ed.6) H01H 9/54, 9/56, 33/59; H02H 7/04, 9/00; H03K 17/64; H05B 3/00, 3/62	Search Examiner MR M J BILLING Date of completion of Search 28 DECEMBER 1995
Databases (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii) ONLINE: WPI	Documents considered relevant following a search in respect of Claims :- 1 to 24

Categories of documents

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P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages		Relevant to claim(s)
X, P	GB 2284100 A	(CARADON) Figure 3; page 8, line 12 to page 10, line 33; published 24 May 1995	1, 2, 3, 4, 9, 10, 12, 13, 15, 16, 21 at least
X	GB 2090702 A	(GENERAL ELECTRIC) Figures 1, 2; Abstract, page 2, lines 24-125	1, 2, 3, 4, 12, 13, 14, 15, 21, 22 at least
X	GB 1503867	(INTERNATIONAL STANDARD ELECTRIC) Figures 1, 2; page 4, line 66 to page 6, line 45	1, 2, 3, 4, 9, 10, 12, 13, 14, 15, 21 at least
X	EP 0589785 A1	(SGS-THOMSON) Figure 2; column 3, line 43 to column 5, line 43	1-6, 12, 13, 21 at least

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Category	Identity of document and relevant passages		Relevant to claim(s)
X	EP 0275960 A2	(DIEHL) Figures 1, 2; Abstract	1, 2, 3, 4, 12, 13, 21, 22
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